(12) UK Patent Application (19) GB (11) 2 228 163 (13) A

(43) Date of A publication 15.08.1990

(21) Application No 8125241.3

(22) Date of filing 18.08.1981

(30) Priority data
(31) 21858 (32) 13.10.1980 (33) FR

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(51) INT CL[5]
H04K 1/00

(52) UK CL (Edition K)
H4L LBSF L1H9

(56) Documents cited
None

(58) Field of search
UK CL (Edition J) **H4L**

(54) **Frequency hopping data transmission**

(57) A data transmission system suitable for military applications comprises a number of networks each including a number of transmission-receiving stations. Each network uses a transmission channel for a brief period only and then jumps to another frequency in a set of frequency channels that is available to the system. No two networks operate on the same channel at any one time. The system provides a solution to the problem which occurs when a remote network transmits on a channel used by another network in the subsequent time slot. The propagation delay may cause interference on the second network. The system, however, overcomes this by dividing the set of channels into sub-sets and successive frequencies channels adopted by the networks are taken from the sub-sets in succession. In one version frequency gaps are incorporated in the sub-sets so that on any one occasion the set of frequencies used by the networks include no two adjacent channels.

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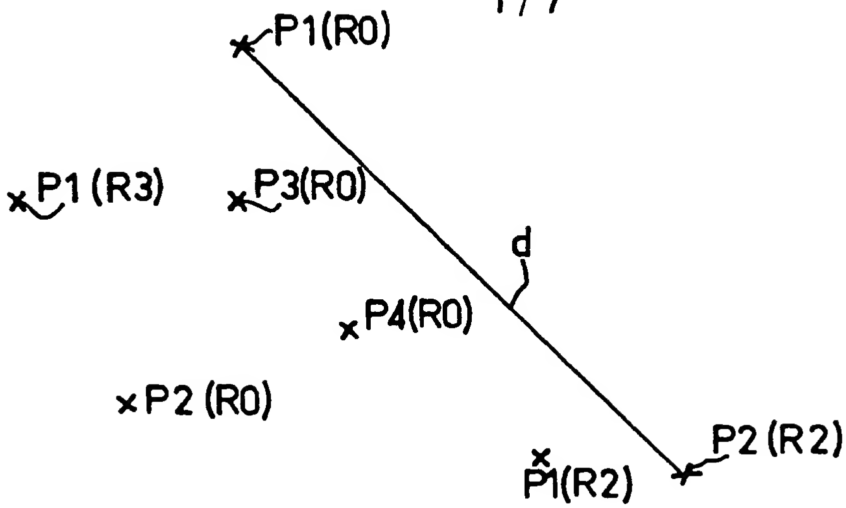

FIG.1

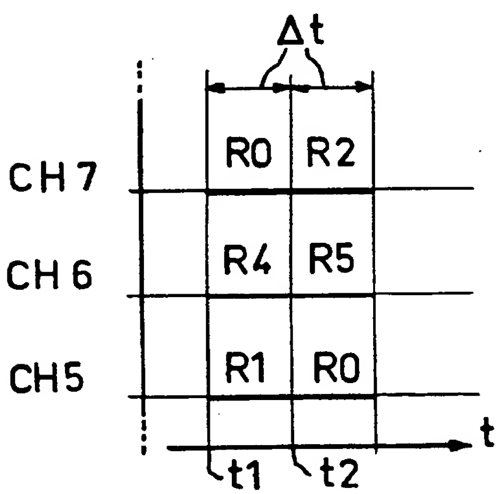

FIG.2

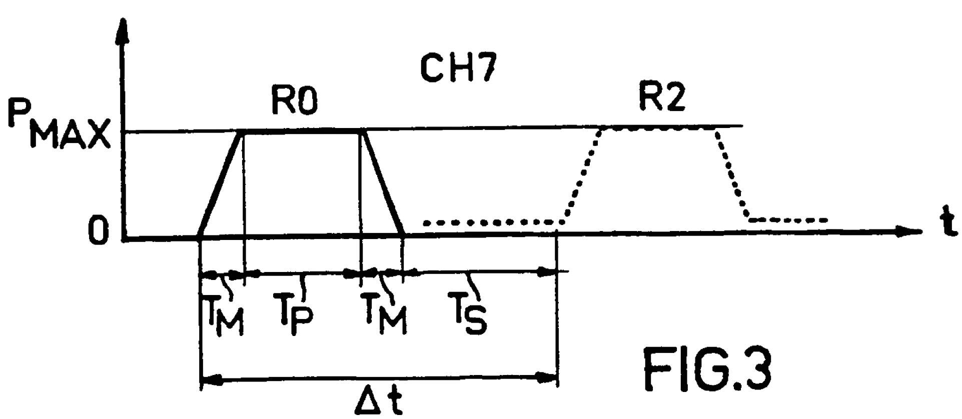

FIG.3

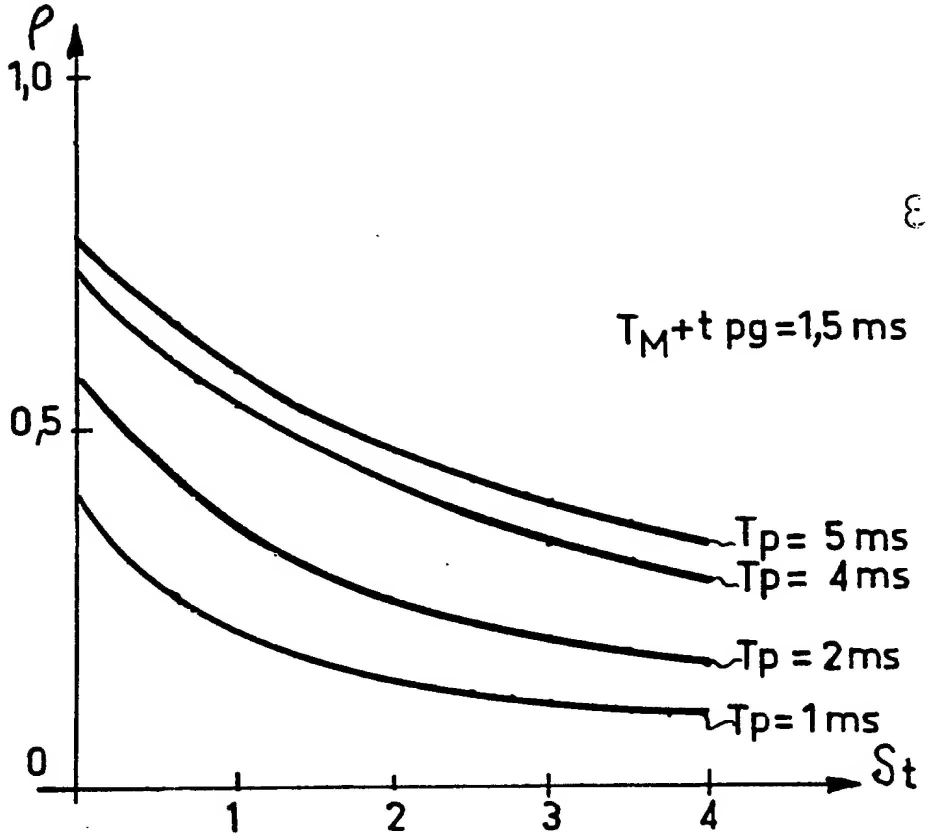
ρ
1,0
0,5
0
T_M+t pg=1,5 ms
Tp= 5 ms
Tp= 4 ms
Tp = 2ms
Tp= 1ms
St
1
2
3
4

FIG.4

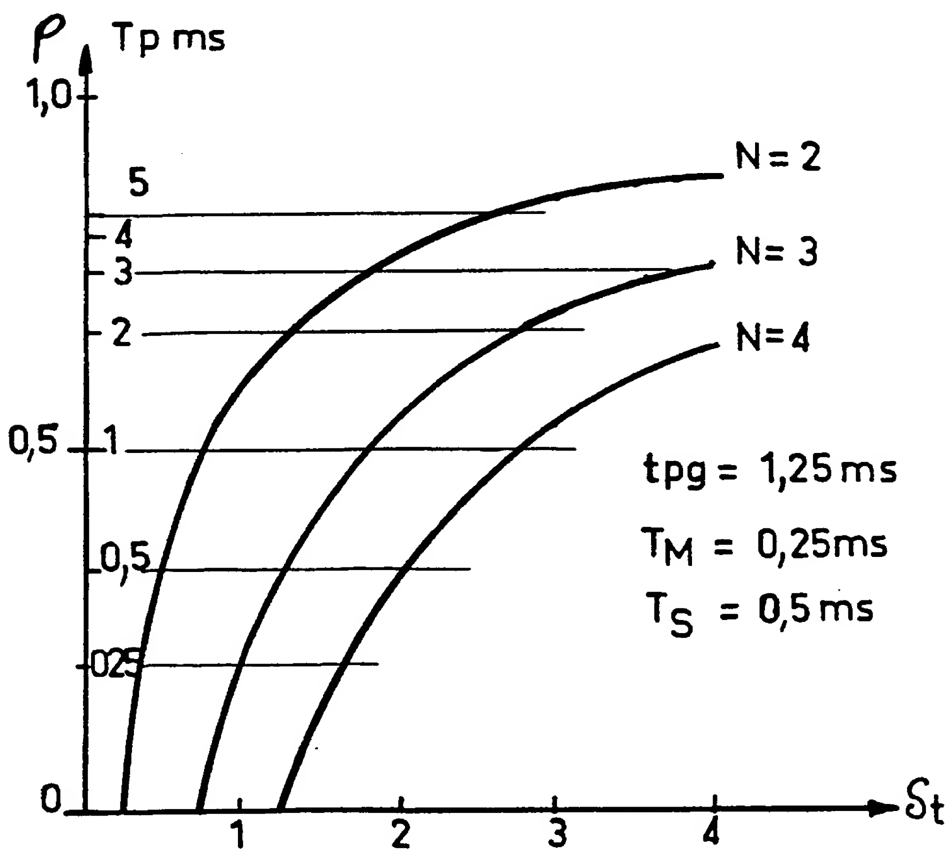
ρ
Tp ms
1,0
0,5
0
5
4
3
2
1
0,5
025
N= 2
N= 3
N= 4
tpg = 1,25 ms
T_M = 0,25ms
T_S = 0,5 ms
St
1
2
3
4

FIG.6

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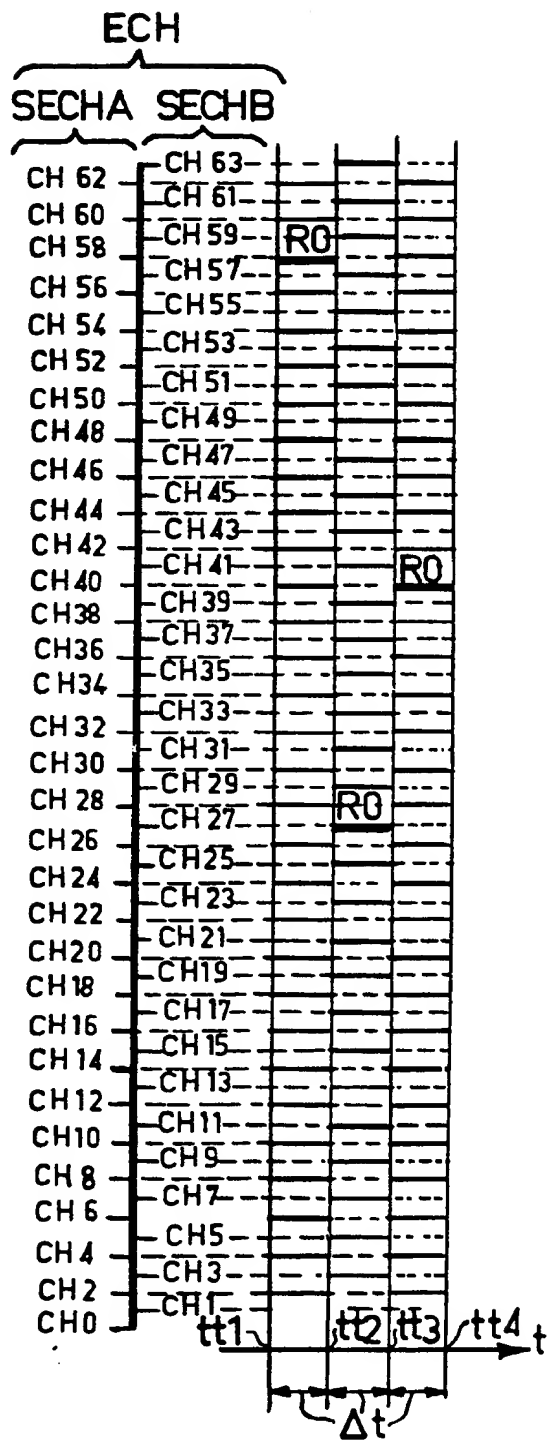

FIG.5

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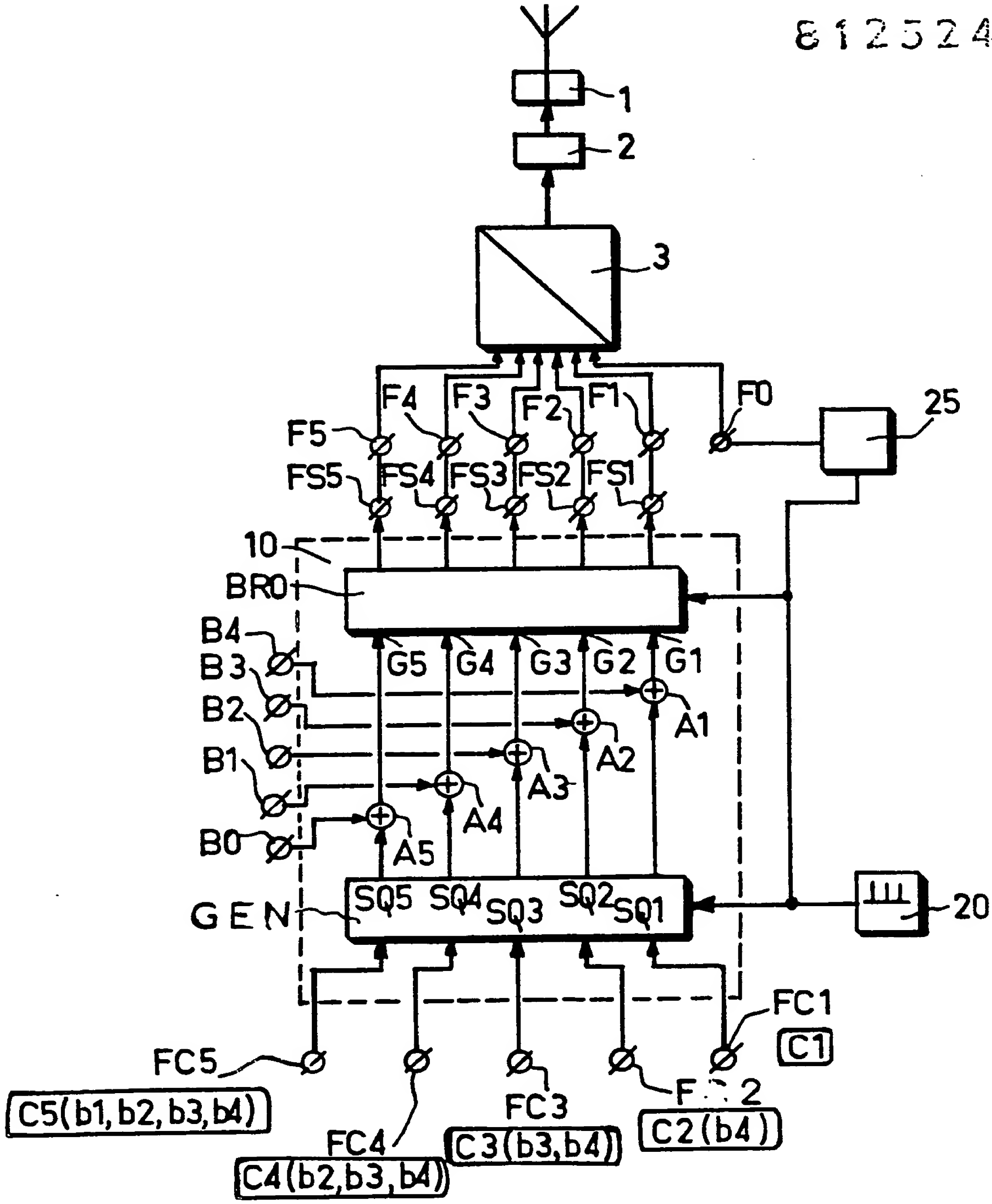

FIG.7

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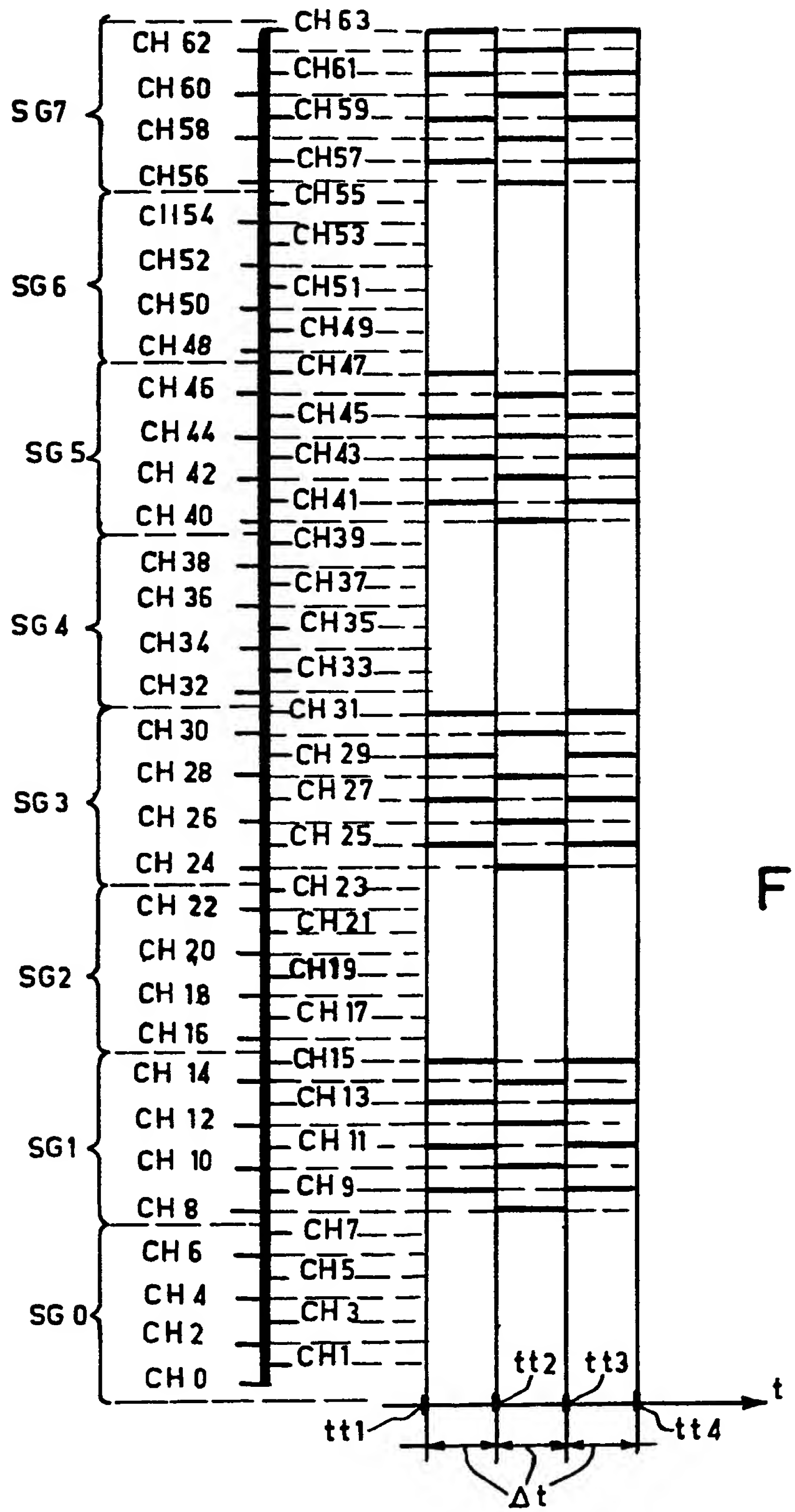

FIG.8

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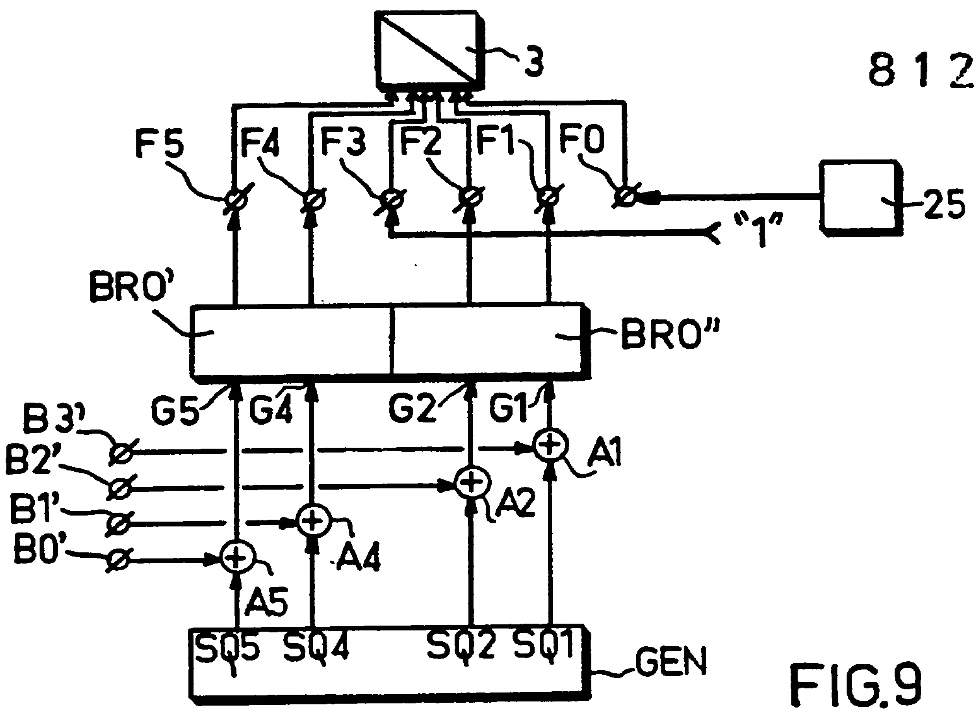

FIG.9

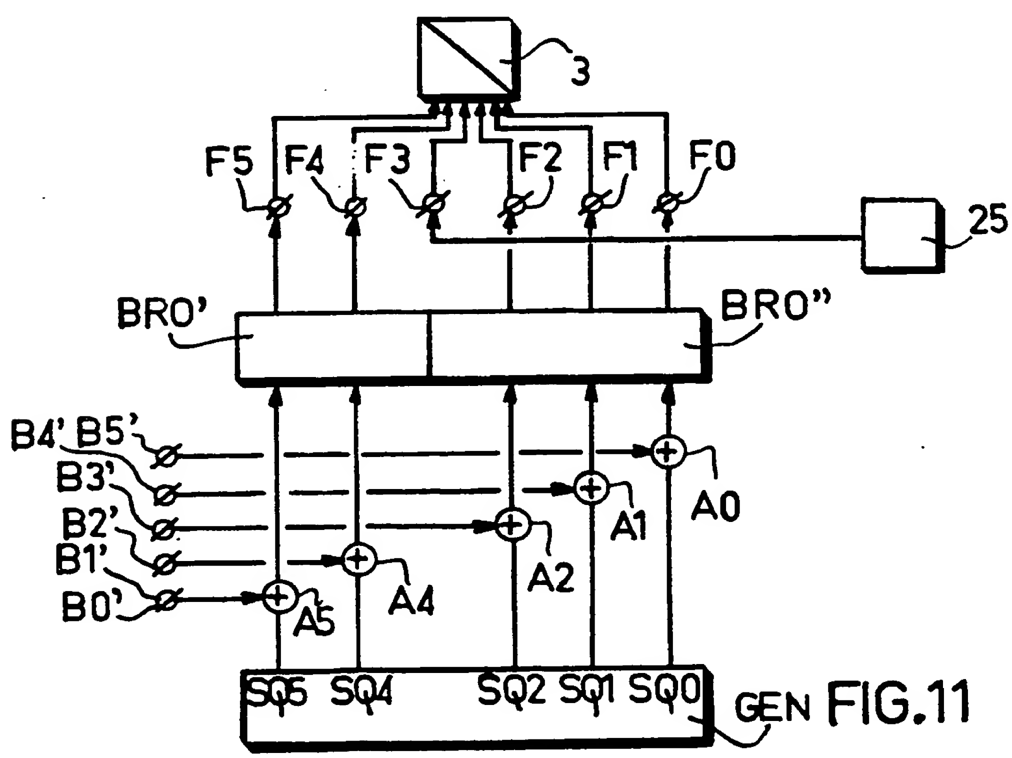

FIG.11

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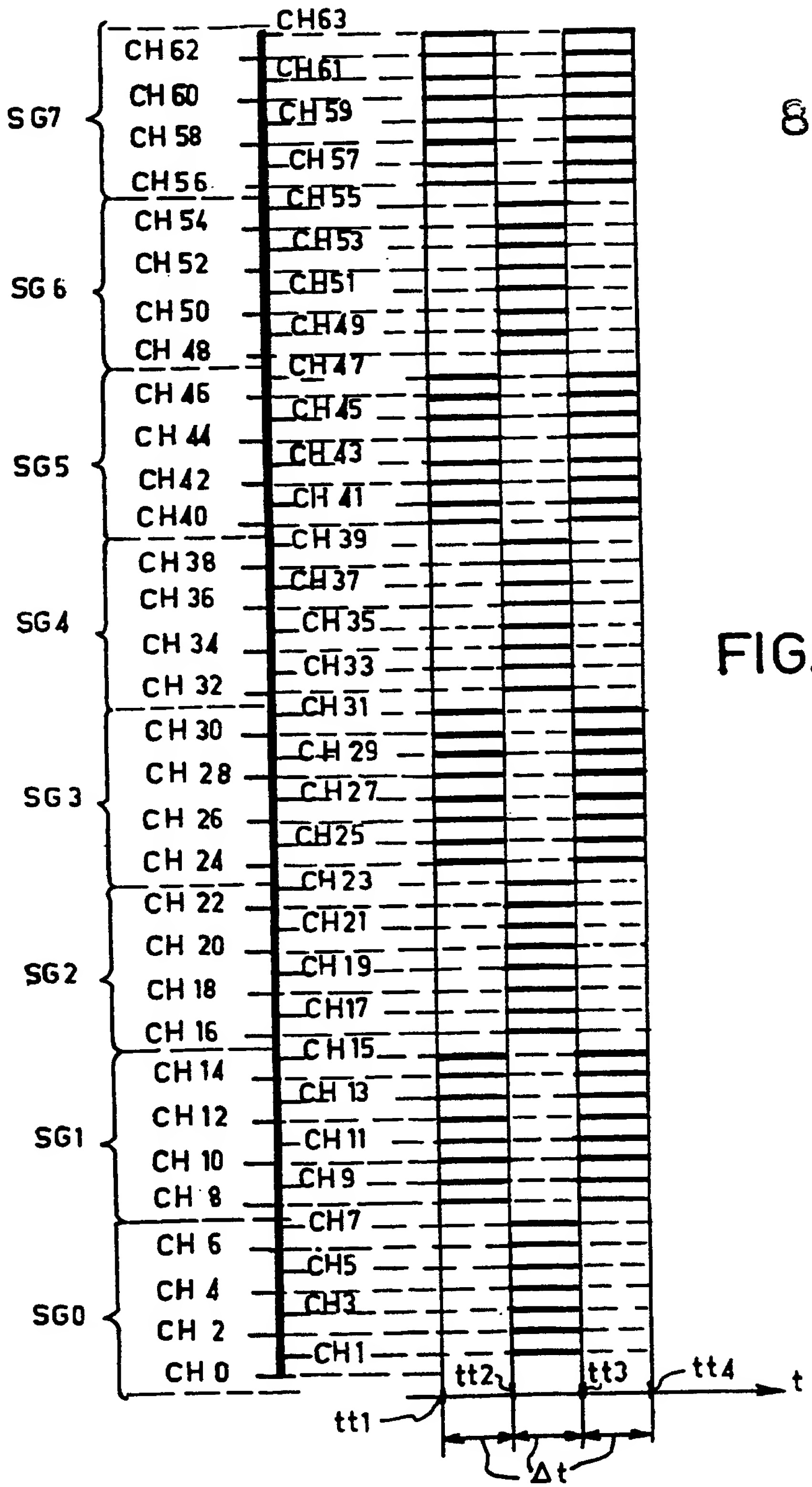

FIG.10

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DESCRIPTION

This invention relates to a data transmission system consisting of networks operating a set of channels by frequency jumps.

The networks concerned in this case are a number of transmission-receiving stations capable of communicating with one another. Each network uses the channels of the set one by one in accordance with a pseudo-random frequency jump or changing law. The frequency changing law of one network must remain unknown to the other networks; the laws under which the different networks are operated must be orthogonal, i.e. there must never at any time be a channel allocated to more than one network.

A system of this kind has important applications in military radio links which are required to be reliable and relatively proof against enemy jamming. The use of one channel out of a very large number for the shortest possible time is considered as an effective means of counteracting enemy jamming.

The following problem arises with this type of system: We shall take the case of a station of a given network which is in the standby position to receive the transmission from a nearby station obviously forming part of this given network. When a frequency jump takes place, the network in question operates a fresh channel. This new channel must not have been used as a transmission channel by a far-off station forming part of another network just before the said frequency jump, because the propagation time taken by the wave transmitted by the far-off station to reach the station on standby will cause interference between the far-off transmission and the transmission of the nearby station.

This invention proposes a system of the kind preferred to in the preamble without the above problem.

To this end, a data transmission system comprising networks operating over a set of channels by frequency jumps is characterised in that the said set is divided into separate sub-sets and each of these sub-sets is used on each jump.

The following description with respect to the accompanying drawings, all of which are given by way of example without any limiting force, will clearly show the advantage of the invention and the way in which it is to be performed.

Figure 1 is a diagram showing the geographical locations of a number of transmission-receiving stations forming part of a system according to the invention.

Figure 2 is a diagram showing the operation of frequency channels.

Figure 3 is a diagram showing the time distribution of the power used to transmit the information in a given channel.

Figure 4 shows the efficiency curves of a system to which the invention has not been applied.

Figure 5 shows a possible use of the available channels according to the invention.

Figure 6 shows the efficiency curves of a system according to the invention.

Figure 7 is a diagram showing a transmission-receiving station embodiment forming part of the system according to the invention for operating channels as shown in Figure 5.

Figure 8 is a first example of operation of channels grouped in sub-bands.

Figure 9 is a diagram showing the embodiment of a transmission-receiving station for the channel operation shown in Figure 8.

Figure 10 shows a second exemplified embodiment of channels grouped in sub-bands.

Figure 11 is a diagram showing an embodiment of a transmission-receiving station for channel operation as shown in Figure 10.

Figure 1 is a very diagrammatic illustration of the geographical location of a number of stations forming part of a system according to the invention. A system of this kind is formed by networks R0, R1, R2, R3, R4, R5 etc. which are groups of stations. Thus in Figure 1 the stations P1 (R), P2 (R0), P3 (R0) and P4 (R0) belong to the network R0 as denoted by the reference in parentheses. Also shown are stations

P1 (R2), P2 (R2), P1 (R3). Each network uses a channel for a time Δt whereafter there is a frequency shift and another channel is used for a time Δt. Thus, referring to Figure 2, at time t1 and for a duration Δt, the stations of network R0 can communicate only via channel CH7, the stations of network R4 can communicate only via channel CH6 and those of network R1 via channel CH5; at time t2 and for a duration Δt the stations of network R0 can communicate only via channel CH5. Channels CH7 and CH6 are used during this period Δt only for the networks R2 and R5 respectively. For the application in question, it should be remembered that this time Δt should be as short as possible so that the minimum amount of data will be useable by the enemy, to prevent him for discovering the channel changing laws.

In order to show the advantage of the invention, we shall now examine what takes place at the times when the channel changes takes place; for example, the time t2 and channel CH7 will be considered. This time t2 will be considered at station P2 (R2). This time is known with an accuracy of δt which is governed by the

synchronism errors of the station clocks. At this time t2, therefore, the stations of network R2 use channel CH7 and the stations of network R0 are on channel CH5. However, if no measures were taken, since station P1 (R0) is at a distance "d" its transmission would still be received by station P2 (R2) for a duration t_{pg} equal to the propagation time taken by the wave to travel from station P1 (R0) to station P2 (R2). This overlapping use of a given channel by two networks is avoided partly by the clearance time T_S between each channel change at the transmitter (See Figure 3). If T_M is the time taken by the transmitter to go from maximum power transmission P_{MAX} to the end of its transmission, and the time taken by the transmitter to restore its power, the following equation applies:

$$(1) \quad T_M + T_S > t_{pg} + 2\,\delta t$$

With a maximum range d = 375 km, then t_{pg} = 1.25 ms, which is greater than the technologically permissible value $T_M + T_S$ = 0.75 ms. T_S must, therefore, be increased to satisfy the inequality (1).

We may define an efficiency ρ representing the percentage of time usable for the transmission of data. If T_P is the duration of effective transmission of the information, then the following applies in respect of ρ :

$$(2) \qquad \rho = \frac{T_P}{T_P + T_M + t_{pg} + 2\,\delta t}$$

It will be apparent that this efficiency decreases continuously with increasing propagation times. To compensate for the adverse effect of this time, it is also possible to improve the accuracy δt of the clocks, but this increases the cost of the equipment.

Figure 4 shows the fall-off in the efficiency ρ against errors δt for various values of T_P, these curves being plotted for $T_M + t_{pg} = 1.5$ ms.

To obviate this considerable reduction, the step proposed according to the invention is to divide the set of channels into N separate sub-sets and use just one of these sub-sets for each frequency change.

Figure 5 shows a set of channels having the references CHO to CH63, the channels forming a set ECH. According to the invention this set is divided, for example, into N = 2 separate sub-sets: SECHA and SECHB. Sub-set SECHA takes the channels bearing an even numerical reference CHO, CH2 - CH62 while sub-set SECHB has an odd numerical reference CH1, CH3 - CH63. To simplify the explanation, we shall examine the case in which these channels are used by a single network, i.e. RO. Thus channel CH58 forming part of the sub-set SECHA is used between the times tt1 and tt2; next channel CH27 of sub-set SECHB is used between times tt2 and tt3, and one of the channels of sub-set SECHB: channel CH40, is used between the times tt3 and tt4.

The efficiency improvement provided by the invention can then be evaluated.

In the case of N, the inequality (1) is replaced by:

$$(3) \quad T_M + T_S + (N-1)\,(T_P + 2T_M + T_S) \geqslant t_{pg} + 2\,\delta t$$

ρ may be written as follows:

$$(4) \quad \rho = \frac{T_P}{T_P + 2T_M + T_S} \quad ,$$

eliminating T_P, the combination of equations (3) and (4) gives:

$$(5) \quad \rho = \frac{2\ \delta t - N\ (2T_M + T_S) + t_{pg} = T_M}{2\ \delta t + t_{pg} - t_M - T_S}$$

Figure 6 shows various efficiency curves. Different values of T_P are shown on the y-axis on the right and equation (4) gives the relationship between ρ and T_P. These curves are plotted for $t_{pg} = 1.25$ ms $T_M = 0.25$ ms and $T_S = 0.5$ ms

It will be clearly seen that ρ and δt cannot be large while T_P and N are small. Comparison with Figure 4 will show the gain obtained in respect of ρ at a given δt.

Figure 7 is a diagram showing a station forming part of the system according to the invention. This station comprises a transmitter-receiver set 1 which provides transmission over the various channels CHO to CH63; the choice of channel is determined by the frequency of a frequency synthesizer 2 which is controlled by means of a transcoder 3; the latter has

input terminals F0, F1, F2, F3, F4, F5 and correlates the 64 channels and the binary code applied to its input terminals and formed by the respective binary elements f0, f1, f2, f3, f4, f5, this correlation being given by the following Table 1:

TABLE 1

f5	f4	f3	f2	f1	f0	Channel
0	0	0	0	0	0	CH0
0	0	0	0	0	1	CH1
0	0	0	0	1	0	CH2
0	0	0	0	1	1	CH3
-	-	-	-	-	-	-
1	1	1	1	1	0	CH62
1	1	1	1	1	1	CH63

The terminals F1, F2, F3, F4, F5 are connected respectively to the outputs FS1, FS2, FS3, FS4, FS5 of a unit 10 which delivers different numerical codes for different identification codes applied to the

terminals B0, B1, B2, B3, B4; a unit of this kind has been described in detail in Applicants' Patent Application No. 80 15 711 filed on 16 July 1980.

Identification codes are used to identify different networks forming part of the system. The different binary elements b0, b1, b2, b3, b4 provide references for 32 networks in the manner indicated in the following Table 2:

TABLE 2

b4	b3	b2	b1	b0	Networks
0	0	0	0	0	R0
0	0	0	0	1	R1
0	0	0	1	0	R2
0	0	0	1	1	R3
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
1	1	1	1	0	R30
1	1	1	1	1	R31

Unit 10 comprises a scrambler BRO, the outputs of which are terminals FS1 to FS5, and which has inputs G1, G2, G3, G4 and G5. This unit may be the unit described in Applicants' Patent Application No. 80 15 506 filed on 11 July 1980. This unit delivers at its outputs a binary word which is the result of a permutation of any order of the binary elements applied to its inputs. To simplify an explanation of the operation of the system it may be considered that this unit BRO effects a zero-order permutation, i.e. everything takes place as if the inputs G1, G2, G3, G4 and G5 were connected directly to the outputs GS1, FS2, FS3, FS4 and FS5. Unit 10 also comprises a set of modulo-2 adders A1, A2, A3, A4, A5, the outputs of which are connected to the inputs G1, G2, G3, G4, G5, the first inputs of these adders A1, A2, A3, A4 and A5 are respectively connected to the terminals B4, B3, B2, B1, B0. The second inputs of these adders receive pseudo-random sequences of binary elements prepared by a pseudo-random sequence generator GEN; the second input of

adder A1 receives a sequence SQ1, the second input of adder A2 receives a sequence SQ2, and so on.

The different sequences depend on a key chosen from a very large number. Thus sequence SQ1 depends on a key C1, sequence SQ2 on a key C2, sequence SQ3 on a key C3, sequence SQ4 on a key C4, and SQ5 on C5. However, to ensure that the codes at the inputs G1, G2, G3, G4 and G5 are orthogonal, some keys will be common to more than one network. Thus key C2 will be common to the networks having the same binary element b4. This key C3 will be common to the networks whose binary elements b4 and b3 are the same; this key will be given the reference C3 (b4, b4); there are also keys C4 (b2, b3, b4) and C5 (b1, b2, b3, b4). The different codes are delivered at the terminals FS1 to FS5 of the unit 10 in the rhythm $1/\Delta t$ of a clock 20. A circuit 25 consisting, for example, of an ordinary trigger circuit delivers a train of binary elements of alternative value 0, 1, 0 etc. so that either the

even channels (CH0, CH2 - CH62) or the odd channels (CH1, CH3 - CH63) will be in use at each Δt.

In a system according to the invention, transmission-receiving stations belonging to different networks may be disposed in close proximity. These stations must, therefore, not interfere with one another.

It is, therefore, necessary to provide high-frequency decoupling of these stations. To this end, the channels used by the networks in question must have a minimum frequency spacing. This minimum spacing is provided by dividing the 64 channels into eight sub-bands SG0, SG1 - SG7. Sub-band SG0 is formed by channels CH0, CH1 - CH7, sub-band SG1 by channels CH8 - CH15, and so on. Only the four sub-bands SG1, SG3, SG5 and SG7 will then be used (see Figure 8) so that there is an unused sub-band of a specific width between each of these sub-bands. Still within the scope of the invention, an even channel or an odd channel will be used alternately on each jump in the sub-band used. The channels that can be used are shown in bold face in Figure 8. Thus the odd channels of sub-bands SG1, SG3, SG5 and SG7 can be used between the times tt1 and tt2 while the even

channels of these same sub-bands can be used between the times tt2 and tt3. Then the odd channels can again be used between the times tt3 and tt4.

Figure 9 is a detail of a transmission-receiving station forming part of a system according to the invention for the use of channels according to Figure 8. The identification code of the networks in this case comprises four binary elements b0', b1', b2', b3' applied respectively to terminals B0', B1', B2' and B3'. These terminals are connected to the first inputs of four modulo-2 adders A5, A4, A2 and A1, the second inputs of which receive the sequences SQ5, SQ4, SQ2 and SQ1 from generator GEN. The sub-bands are defined by the binary elements present at the inputs F5, F4, F3 of the converter; since binary element f3 is permanently "1", the only sub-bands used will be those whose reference has an odd number. The scrambler circuit BRO consists of two parts BRO' and BRO''. Part BRO' provides any permutation between the binary elements present at its terminals G5 and G4 to restore them to the inputs F5 and F4, the terminals

G5 and G4 being connected to the outputs of the adders A5 and A4. Part BRO'' provides any permutation between the binary elements present at its input G2 and G1 to restore them at the terminals F2 and F1, terminals G2 and G1 being connected to the outputs of the adders S2 and A1. Terminal FO is connected to the output of unit 25 which delivers logic "1" and logic "0" alternately.

The set of channels can be divided in some other way. For example, again referring to sub-bands, as shown diagrammatically in Figure 10 a first sub-set may comprise all the channels (i.e. both the odd and even channels) of the sub-bands having an odd reference numeral, i.e. sub-bands SG1, SG3, SG5 and SG7, while the second sub-set includes all the channels of the sub-bands whose reference numeral is even; of course on each jump there will be a change from one sub-set to the other. Figure 11 shows the way in which sub-sets can be obtained. The number of sub-bands is governed by the binary elements applied to the terminals F5, F4, F3. To go from the even-reference sub-bands

to odd-reference sub-bands, terminal F3 is connected to circuit 25. Terminals F5 and F4 are connected to a part BRO' of the scrambler circuit, the terminals F2, F1, FO of the converter are connected to the outputs of the second part BRO'' of the scrambler circuit, the parts BRO' and BRO'' operate independently of one another but at the same rhythem. The inputs of circuit BRO' are connected to the outputs of modulo-2 adders A5 and A4 and those of the circuit BRO'' to the outputs of the adders A2, A1, AO. The inputs of these adders A5, A4, A3, A2, A1, AO receive the binary identification code applied to the terminals BO', B1', B2', B3', B4', B5'. The second inputs of these adders receive the binary elements of the sequences SQ5, SQ4, SQ2, SQ1 and SQ respectively delivered by generator GEN; this latter procedure shown in Figures 11 and 10 uses the set of channels available to the best advantage in cases in which high-frequency decoupling is required.

CLAIMS

1. A data transmission system comprising a plurality of networks each adapted to operate over a set of frequency channels and to repeatedly jump in synchronism between frequency channels during transmission, wherein the networks include means for selecting the transmission channel from predetermined sub-sets of said set of frequency channels, said means being synchronised between the networks such that the channel to which a network jumps is from a sub-set which was not utilised by one of the networks in the preceding transmission period.

2. A data transmission system as claimed in claim 1 wherein the networks are synchronised such that in any one transmission period, each transmitting network utilises a frequency channel from the same sub-set.

3. A data transmission system as claimed in claim 1 or claim 2 wherein, each network is identified

by an identification code, and each combines a plurality transmission/receiving stations each including said means for selecting a transmission channel, the means comprising a frequency synthesizer determining the channel frequency, a transcoder operative to control the frequency synthesizer in accordance with numerical coded signal supplied to the transcoder,

means for producing a succession of said numerical coded signals in dependence on the identification codes and supplying these to the transcoder.

4. A data transmission system as claimed in claim 3 wherein each transmission/receiving station includes a source of alternating numerical data, operative to supply said data to said transcoder,

the data being indicative of particular ones of said sub-sets of the frequency channels and being utilized by the transcoder to alternate the frequency of the frequency synthesizer to alternate ones of said sub-sets.

5. A data transmission system as claimed in claim 1 or claim 2 wherein the frequency channels included in any one sub-set are each separated by frequency channels included in said set of frequency channels but not in said one sub-set of channels.

6. A data transmission system substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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